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Influence of Welding Regimes and Filler Metals on Hardfaced Layers for Precision Mechanical Components Made of 30CrMoV9 Steel

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Abstract: This work examines how different welding regimes and filler metal types influence the characteristics of hardfaced layers and the associated heat-affected zones (HAZ) in components made of low-alloy steel 30CrMoV9. Bead-on-plate welding tests were carried out on plate specimens, using five filler metals, including four gas-shielded wires with different chemical compositions and one flux-cored wire. For each filler metal, two welding regimes were applied by varying the current, voltage, and travel speed. After welding, the bead geometry and hardness were measured, and bending tests were performed to assess cracking behavior. The results show that both filler metal selection and arc energy have a pronounced effect on bead shape and hardness, as well as on the hardness distribution in the HAZ. It is also observed that, because of the metallurgical characteristics of 30CrMoV9 steel, preheating and/or post-weld heat treatment is required to reduce the risk of cracking. The findings may serve as practical input for process selection and quality control in the fabrication and repair of precision mechanical parts.

Keywords: Welding; Hardfacing; Filler material; Precision mechanical components; Weld bead bending test

1 Introduction

Low-alloy steels are widely used in precision mechanical components because they provide a favorable combination of strength, hardness, and toughness at a reasonable cost, which makes them suitable for demanding parts such as gears, shafts, and tooling [1, 2]. During service, components made of these steels are often subjected to wear and degradation, which may reduce their load-bearing capacity and functional reliability, making repair or replacement necessary. Hardfacing is a widely used repair technique in which a layer of hard, wear-resistant material is deposited onto a worn surface in order to restore its functionality. Welding is one of the most commonly used methods for applying hardfacing layers, using appropriate filler metals as the deposited material. It is particularly attractive for repair applications because it can be applied to components with complex geometries using different joint configurations and welding techniques [3–5]. Therefore, the selection of suitable filler metals and welding parameters is a key issue in ensuring the reliability of repaired components. It is also essential to understand how repair welding affects the mechanical properties of the weld bead and whether the load-bearing capacity of the repaired component can approach that of the original material. In many cases, post-weld heat treatment is required to achieve mechanical properties comparable to those of the base material (BM). Accordingly, this paper investigates hardfacing by welding on plate specimens made of low-alloy steel 30CrMoV9, using different filler metals and welding regimes [6–9].

2 Experimental Part with Results

The steel plates with dimensions of 150 × 80 × 10 mm were used for hardface welding. The BM is the low-alloy steel 30CrMoV9 of chemical composition given in Table 1 [1].

Table 1. Chemical composition of the base material (BM)-low-alloy steel 30CrMoV9 (1.7707), %

C	Si	Mn	Ni	P	S	Cr	Mo	V
0.26–0.34	max 0.4	0.4–0.7	max 0.6	max 0.035	max 0.035	2.3–2.7	0.15–0.25	0.1–0.2

Weld beads of various fillers were applied onto the 30CrMoV9 plates (Figure 1) by different single pass welding regimes of semi-automatic welding, using CO_2 protective gas (C type [2]). Four fillers in the form gas shielding welding wire (diameter 1.2 mm) and one filler as flux-cored wire (No. 5) were used. The chemical composition of the fillers is given in Table 2.

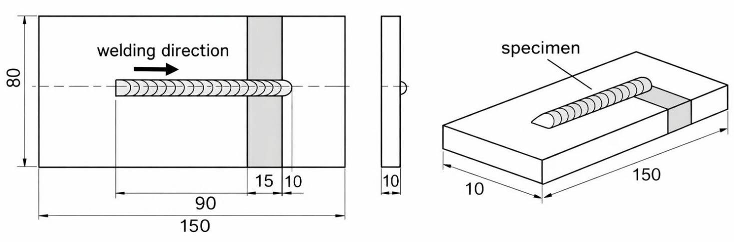

Figure 1. Hardface welded steel plate

Table 2. Filler metal designation and chemical composition

No.	Designation		Chemical Composition, %					
	ASW [4]	Other Standards	C	Si	Mn	Ni	Cu	S
1	ER70S-6	SG-2 (DIN); 3Si1 (EN) [3]	0.087	0.83	1.86	0.12	/	0.018
2	ER70S-6	SG-3 (DIN); 4Si1 (EN) [3]	0.087	0.95	2.21	0.12	/	0.018
3	ER70S-G	/	0.088	0.99	1.90	1.26	/	0.012
4	ER70S-G	/	0.102	0.93	1.73	0.54	0.47	0.012
5	ER110TS-K4	/	0.150	0.80	1.73	2.18	/	0.03

The welding input parameters, electricity, voltage, and welding speed (travel speed of the welding torch) are varied for every type of filler metal. Each of the five used fillers was welded on the plate by two regimes. The welding regime parameters are presented in Table 3.

Table 3. Welding regimes

Weld Regime WR No.	Filler (Table 2)	Welding Input Parameters				
		Current IA	Voltage UV	Welding Speed (cm/s)	Arc Energy (J/cm)	Heat Input (HI, H = 0.75, J/cm)
1	1	120	20	0.875	2742.9	2057
2	1	170	22.5	0.470	8138.3	6104
3	2	120	20	0.875	2742.9	2057
4	2	175	20	0.875	4000.0	3000
5	3	120	20	0.875	2742.9	2057
6	3	175	23	0.824	4884.7	3664
7	4	170	23	0.933	4314.0	3236
8	4	170	22.5	0.481	7952.2	5964
9	5	120	20	0.636	3773.6	2830
10	5	170	22.5	0.875	4371.4	3279

Based on the values of current I, voltage U, and welding speed v, the energy supplied by the welding arc to the hardfacing plate is calculated by the following equation:

$$\mathrm{AE} = \frac{UI}{v} \tag{1}$$

Calculated arc energy, depending on welding fillers and regimes is given in Table 3. Heat input considers the influence which process efficiency has on the energy that reaches the workpiece to form the weld. HI is given by the equation:

$$\mathrm{HI} = \eta \mathrm{AE} \tag{2}$$

Heat input, calculated based on arc energy considering the efficiency of 75% is given in Table 3. After welding, specimens (of width 15 mm) were cut from the test plates (Figure 1), which were used to measure dimensions and hardness of the weld beads, as well as for bend testing. The measured cross-sectional dimensions of the weld beads are shown in Figure 2 and measured values (bead width, reinforcement height and penetration depth) are given in Table 4.

Based on the measured weld bead dimensions, the weld penetration shape factor is:

$$WPSF = \frac{w}{P} \tag{3}$$

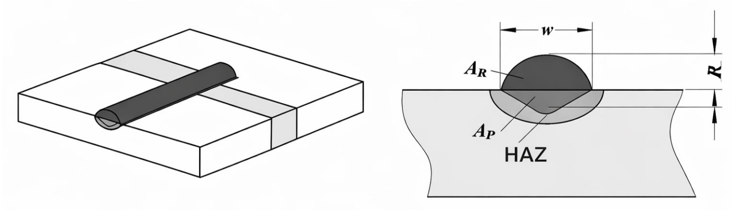

Figure 2. Cross-section of the weld bead (R—reinforcement; P—penetration; w—width)

Dilution—the area of base metal melted in relation to the cross-sectional area of the bead (Figure 2) was determined using the formula:

$$D = \frac{A_\mathrm{p}}{A_\mathrm{R} + A_\mathrm{p}} 100\% \tag{4}$$

Table 4. Geometry parameters of the weld bead

Welding Regime (Table 3)	Bead Width w mm	Reinforcement Height R mm	Penetration Depth P mm	Bead Height $R + P$ mm	Weld Penetration Shape Factor $WPSF$	Dilution D %
1	5.5	1.8	1.3	3.1	4.2	41
2	10.0	3.5	2.2	5.7	4.5	38
3	5.5	1.7	1.3	3.0	4.2	43
4	7.0	2.9	1.8	4.7	3.9	38
5	5.5	1.8	1.4	3.2	4.0	43
6	7.5	2.3	2.2	4.5	3.4	50
7	6.3	2.1	2.0	4.1	3.1	49
8	10.0	3.3	2.2	5.5	4.5	40
9	5.0	1.9	1.4	3.3	3.6	42
10	8.0	2.7	1.3	4.0	6.2	32

The hardness of the weld bead reinforcement area was measured, as well as the heat-affected zones (HAZ) hardness on different distances from the hardfaced surface (Table 5). The hardness distribution in HAZ is shown by the diagram in Figure 3.

Table 5. Hardness of bead and heat-affected zones (HAZ)

No.	Bead Hardness Vickers Hardness 5 (HV5)	HAZ Hardness HV5												
		0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1	1.25	1.5	1.75	2
1	420	-	-	-	-	-	-	-	-	-	-	-	-	-
2	371	-	-	-	-	-	-	-	-	-	-	-	-	-
3	516	589	625	558	535	530	492	410	342	386	386	380	386	386
4	441	549	565	553	551	551	515	437	414	321	365	390	386	386
5	491	560	584	544	544	545	499	380	306	381	371	380	386	381
6	488	559	630	622	610	570	545	501	457	336	350	370	392	390
7	479	562	572	565	551	535	532	450	438	356	364	401	390	392
8	367	489	494	490	470	470	439	427	419	410	324	337	390	371
9	445	558	568	568	560	537	508	465	361	330	376	394	394	386
10	453	509	531	525	525	520	511	478	468	343	328	394	386	386

The hardness of HAZ is high near to the bead, decreasing under the hardness of the BM, on the depth of approx. (0.2–0.5) mm (Figure 3).

The scheme of the bend test is shown in Figure 4. The weld bead is in the tension zone of the bent specimen. During the test, each specimen was bent until the first crack appeared on the weld bead. At that moment, the bending angle α (Figure 4) was registered (Table 6).

3 Discussion

Under the applied experimental conditions, the relatively large mass of the test plates compared to the deposited bead, together with the high proportion of BM in the fused zone, resulted in high bead hardness and limited plasticity. When higher arc energy and heat input were applied, lower bead hardness and larger bending angles at the onset of cracking were observed [10–12].

On the basis of the results presented in Tables 4, 5, 6, the following observations can be made:

- Under all applied regimes, the reinforcement height exceeded the penetration depth into the BM;

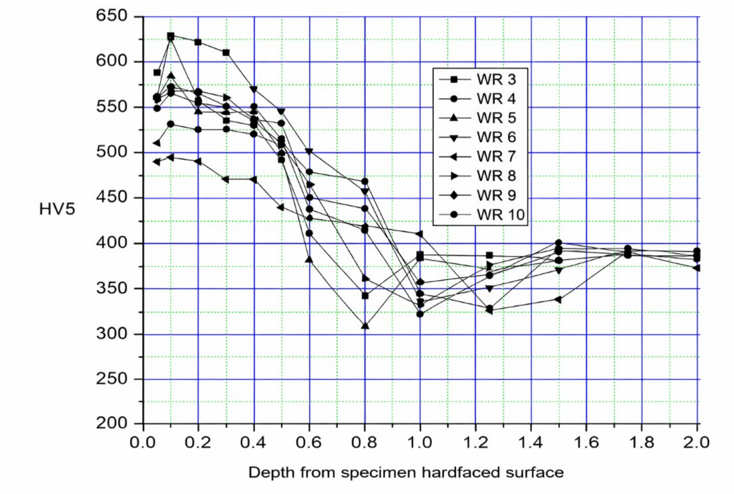

Figure 3. Hardness distribution in the heat-affected zones (HAZ) area

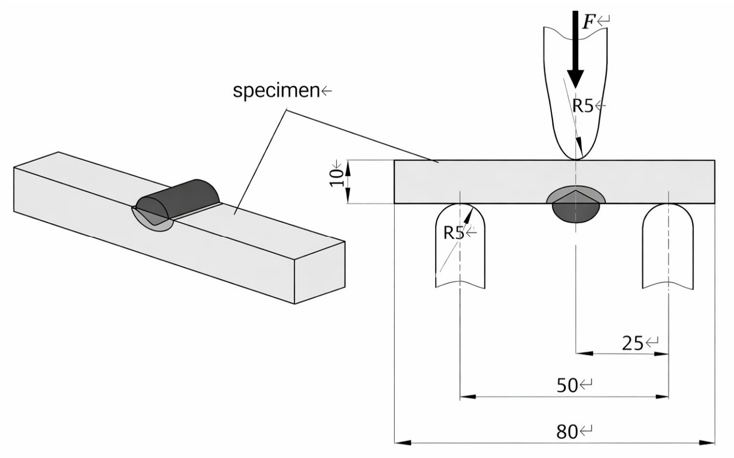

Figure 4. Weld bead bend test

Table 6. Bending angle corresponding to the first crack appeared on the weld bead

Weld Regime (Table 3)	Bending Angle α (°)
1	7.2
2	11.3
3	5.4
4	7.0
5	8.0
6	8.3
7	7.1
8	14.0
9	10.0
10	12.2

- With increasing arc energy and heat input, the bead width increased accordingly;
- For flux-cored wire (regimes 9 and 10), smaller penetration depths were obtained at comparable arc energies and heat inputs than for gas-shielded wires, resulting in higher values of the weld penetration shape factor (WPSF);
- Although penetration depth generally increased with arc energy and heat input, no clear relationship was found between the penetration area A_P and the total bead cross-sectional area A_R;
- The bending angle at the onset of cracking increased with arc energy, heat input, and bead width, but decreased with increasing bead hardness.

The hardness distribution in the HAZ is shown in Figure 3. Under the applied welding conditions, relatively high hardness values were measured close to the bead, followed by a decrease at depths of approximately 0.2–0.5 mm to values below the original BM hardness [13–26].

4 Conclusions

The results show that the mechanical characteristics of the weld bead and the heat-affected zone in hardfaced 30CrMoV9 steel are strongly influenced by the choice of filler metal and the applied arc energy (i.e., heat input). For precision mechanical components made of this steel, which require high resistance to cracking, preheating and/or post-weld heat treatment is therefore necessary. The present study provides experimental data that can support the selection of welding parameters and filler materials for hardfacing applications involving 30CrMoV9 steel.

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Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The author declares no conflict of interest.

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